

**LANTHANIDE OXIDE/ZIRCONIUM OXIDE ATOMIC LAYER DEPOSITED  
NANOLAMINATE GATE DIELECTRICS**

**ABSTRACT OF THE DISCLOSURE**

The invention provides a laminated dielectric layer for semiconductor devices formed by a combination of  $\text{ZrO}_2$  and a lanthanide oxide on a semiconductor substrate and methods of making the same. In certain methods, the  $\text{ZrO}_2$  is deposited by multiple cycles of reaction sequence atomic layer deposition (RS-ALD) that includes depositing a  $\text{ZrI}_4$  precursor onto the surface of the substrate in a first pulse followed by exposure to  $\text{H}_2\text{O}/\text{H}_2\text{O}_2$  in a second pulse, thereby forming a thin  $\text{ZrO}_2$  layer on the surface. After depositing the  $\text{ZrO}_2$  layer, the lanthanide oxide layer is deposited by electron beam evaporation. The composite laminate zirconium oxide/lanthanide oxide dielectric layer has a relatively high dielectric constant and can be formed in layers of nanometer dimensions. It is useful for a variety of semiconductor applications, particularly for DRAM gate dielectric layers and DRAM capacitors.

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